EFFECTS OF CUT-OUT ON NATURAL FREQUENCY OF GLASS FIBRE-EPOXY COMPOSITE PLATES

A Thesis Submitted In Partial Fulfilment
of the Requirements for the degree of

Bachelor of Technology
IN
Civil Engineering

BY

DEBASIS BASA (108CE016)

SUBHRANSHU DWIBEDI (108CE031)

Under supervision of

Prof. SHISHIR. KUMAR. SAHU

Department of Civil Engineering
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INDIA

CERTIFICATE

This is to certify that the thesis entitled, "**Effects Of Cut-out On The Natural Frequency Of Glass Fibre – Epoxy Composite Plates**" submitted by Mr. Subhranshu Dwibedi and Mr Debasis Basa in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

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CONTENTS

		Page No
ABSTRACT		**I**
LIST OF TABLES		**II**
LIST OF FIGURES		**IV**
CHAPTER 1	**INTRODUCTION**	**1**
	1.1 COMPOSITE OVERVIEW	**2**
	1.2 IMPORTANCE OF CUT-OUT	**3**
CHAPTER 2	**LITEATURE REVIEW**	**4**
	2.1 PREVIOUS STUDIES UNDERTAKEN	**5**
	2.2 SCOPE OF PRESENT WORK	**9**
CHAPTER 3	**EXPERIMENTAL PROGRAM**	**11**
	3.1 GENERAL OVER VIEW	**12**
	3.2 FABRICATION TECHNIQUE	**14**
	3.3 EXPERIMENTAL SETUP	**16**
	3.4 EXPERIMENTAL PROCEDURE	**20**
CHAPTER 4	**MATHEMATICAL MODELLING**	**22**
CHAPTER 5	**RESULTS AND DISCUSSIONS**	**26**
	5.1 MODAL TESTING OF AL BAR	**27**
	5.2 MODAL TESTING OF COMPOSITE LAMINATES WITHOUT CUT-OUT	**27**
	5.3 MODAL TESTING OF COMPOSITE LAMINATES WITH CUT-OUT	**29**
CHAPTER 6	**CONCLUSION**	**44**
REFERENCES		**47**

ABSTRACT

Excellent mechanical properties of composite laminates combined with high stiffness and light weight have been an active field of research for decades. Industry now a day is also promoting the use of composites over other conventional materials for structural purposes. Keeping that in mind, it is utmost important to determine the static and vibrational characteristics of composite plates. Composite plates used as structural elements are generally subjected to various shapes, sizes and design of cut-outs. These cut-out servers for various practical uses for the designers. In this study basically the study of the modal characteristics of the glass fibre epoxy composite plates in the presence of different cut-outs was taken up. The study was a combination of experiments and analytical modelling. Parameters such as size of cut-out, different thickness of plate with same size of cut-out, distance of cut-out from support and relative position of the cut-out was studied. The variation in the mode frequencies and mode shapes were investigated for all the above cases.

For modal analysis, a Fast Fourier Transform Analyser, Pulse lab shop software, Accelerometer was used. From this we obtained the frequencies of the first four modes. The results obtained by the Pulse were then compared with the data obtained from the Ansys modelling. Detail mode shapes for various conditions were retrieved from Ansys. First the analysis of the composite plates without cut-outs was done. Then cut-outs were introduced in the plates. Results from the modal analysis and Ansys were found to have very less variation. The Variations of natural frequency with different parameters are presented.

LIST OF TABLES

Table 4.1: Material properties of E Glass fibres.

Table 4.2: Constraints for various boundary conditions used

Table 4.3: Data for Block Lanczos Method of modal analysis.

Table 5.1.: Modal Frequencies of Aluminium bar from experiment.

Table 5.2: Modal Frequencies of Aluminium bar from Ansys modelling

Table 5.3: Modal Frequencies of 8 layer Composite Laminates for different end conditions

Table 5.4: Modal Frequencies of 12 layer Composite Laminates for different end conditions.

Table 5.5: Modal Frequencies of 16 layer Composite Laminates for different end conditions

Table 5.6: Modal Frequencies of 8 layer Laminates with 6x6 central cut-out

Table 5.7: Modal Frequencies of 8 layer Laminates with 8x8 central cut-out.

Table 5.8: Modal Frequencies of 8 layer Composite Laminates with 10x10 central cut-out.

Table 5.9: Modal Frequencies of 8 layer Composite Laminates with a central cut-out of Aspect Ratio of 2.

Table 5.10: Modal Frequencies of 8 layer Composite Laminates with a central cut-out of Aspect Ratio of 3.

Table 5.11: Modal Frequencies of 12 layer Composite Laminates with a central cut-out of 6x6.

Table 5.12: Modal Frequencies of 16 layer Composite Laminates with a central cut-out of 6x6.

Table 5.13: Modal Frequencies of 8 layer Composite Laminates with a corner cut-out of 6x6.

Table 5.14: Modal Frequencies of 8 layer Composite Laminates with a side cut-out of 6x6.

Table 5.15: Modal Frequencies of 8 layer Composite Laminates with a cut-out of 6x6 at a distance of 6 cm from support.

Table 5.16: Modal Frequencies of 8 layer Composite Laminates with a cut-out of 6x6 at a distance of 18 cm from support.

LIST OF FIGURES

Figure 3.1: Time response function.

Figure 3.2: Frequency Response Function.

Figure 3.3: Hand Lay-up process.

Figure 3.4: Industrial Hand Lay-up process in a mould.

Figure 3.5: Accelerometer Brüel&Kjær (4507).

Figure 3.6: Modal hammer Brüel&Kjær (2302-5).

Figure 3.7: FFT Analyzer.

Figure 3.8: Connections of Modal Hammer and Accelerometer with the FFt Analyzer.

Figure 3.9: Experimental setup.

Figure 3.10: Frame used for the modal testing of composite plates .

Figure 3.11: Fabrication Setup.

Fig 4.1: Element of Shell 99.

Fig 4.2: Meshing of an 8cm * 8cm cut-out plate.

Figure 5.1: Variation between modal frequencies with change in size of cut-out for cantilever end condition.

Figure 5.2: Variation between modal frequencies with change in size of cut-out for fixed end condition.

Figure 5.3: Variation between modal frequencies with change in size of cut-out for simply supported end condition.

Figure 5.4: Variation between modal frequencies with change in aspect ratio for cantilever end condition.

Figure 5.5: Variation between modal frequencies with change in aspect ratio for simply supported end condition.

Figure 5.6: Variation between modal frequencies with change in aspect ratio for fixed end condition.

Figure 5.7: Variation between modal frequencies with change in no. of layers for cantilever end condition.

Figure 5.8: Variation between modal frequencies with change in no. of layers for simply supported end condition.

Figure 5.9: Variation between modal frequencies with change in no. of layers for fixed end condition.

Figure 5.10: Variation between modal frequencies with change in position of cut-out for simply supported end condition.

Figure 5.11: Variation between modal frequencies with change in position of cut-out for fixed end condition.

Figure 5.12: Variation between modal frequencies with change in distance cut-out from support for (cantilever end condition).

CHAPTER 1

INTRODUCTION

COMPOSITE MATERIAL OVERVIEW

Composite materials are those materials which are obtained by the combination two materials. One is the reinforcements and the other is the matrix. The reinforcements are responsible for carrying the loads and the stresses which the composite is subjected to. The work of the matrix if to distribute the force and stress uniformly among the reinforcement and binds the reinforcement. It also prevents the fibres from external damage. Composite materials are such that they inherit the superior qualities of the combining materials leaving behind the inferior qualities.

The properties which are impossible to be obtained from a single material can be obtained from a composite due to its heterogeneous nature. All the properties of the composites are the function of its constituent materials, their spatial distribution and particle interaction between them.

The excellent stiffness to weight ratio, specific strength and other required properties of Fibre reinforced laminates make them first and foremost choice of designers in structural applications. Several types of elements such as plates shells etc. have been successfully implemented in many real life structures which are showing excellent properties. For designer and engineers composites come as a viable solution for many structural problems such as structural health up gradation, crack prevention etc.

In all branches of engineering there are always two fundamental methods of solving a problem – analytical or numerical modelling and experimental measurements. Both of them are an integral aspect of a research work. These days due to the advancement in the field of computing several Finite Element Packages have come up which make the modelling and simulation of problems easier. Further due to the advancement in the computer aided data acquisition systems, Experimental Modal Analysis has become an extremely important tool for an experimentalist.

IMPORTANCE OF CUT-OUTS:

Cut out is an integral part of almost every structural element including laminated composite plates. They are used in civil, mechanical, aerospace and automotive industry extensively. For various practical reasons we always need to provide cut out in these structures. Cut-outs serve the purpose of access vents for the mechanical and electrical systems such as passage of electrical wires, hydraulic lines etc . many times designers just use cut-outs of various shapes and size for quality control, to reduce the weight the weight of structures and also to alter the natural frequencies of structures to make them safe in case of hazardous vibrations .

Cut-outs in structural members like plates tend to change its dynamic characteristics to some extent. This change is obvious whenever the structure is exposed to large vibrations. Many a times these cut-outs may lead to failure under lower stress and also sometimes due to undesired resonance. So it is utmost necessary to predict the resonant frequencies of these structures with cu-touts. The extensive range of practical applications of cut-outs in plates requires a better understanding of the vibrations and stability properties of laminated plates with cut-outs.

CHAPTER 2

LITERATURE REVIEW

PREVIOUS WORKS CARRIED OUT ON THE TOPIC:-

As stated in the introduction, the vibration and stability studies of composite plates is an active and advanced field of research. Among the various composites ,Fibre reinforced polymer(FRP) composite is the most widely used for study because of their superior properties such as high strength , light weight and many other attractive dynamic characteristics such as Damping and High Stiffness. But the reliability of the materials depends of the proper assessment of the various static and dynamic properties of the composite and their behaviour under different loading and atmospheric conditions**.** In the field of laminated composite plates incorporating cut-outs extensive research was done in the past three decades covering various aspects and parameters. Some of the previous studies have been summarized below.

In composite plates testing and analysis much progress has been done in the past three decades. Systematic analysis of composite plates started since the formulation of Reissner and Stavsky[1] by extending Krichhoff's theory to laminated plates .Further numerical analysis was carried out by Yang, Norris and Stavsky [2] who extended Midlin shear deformation theory to laminated plates. But all the research was mainly concentrated on the numerical analysis with minimal or no experimental works. Whatever experimental works wear done they were mostly based on uni directional fibre alignment.

Linear vibration analysis of laminated rectangular plates has been done by Han and Petyt[3]. In recent times works have been done by Chakraborty et.al [4] regarding free vibration responses of FRP composite. Both experimental and numerical studies had been done. In the experimental part modal testing have been done using modal hammer and supported instruments to get the frequency response of the plates. The results obtained were matched with the finite element code developed indigenously. Again a finite element package known as NISA was used to authenticate the data obtained. The data from the package and the experiment showed very less deviation.

Lei,Rui et al [5] studied the effect of different woven structures of the glass fibre on the dynamic properties of composite laminates. Composite plates of appropriate techniques were prepared in fabric processing. The composite plates were tested with various vibration analysing techniques to determine their vibrational and dynamic behaviour. Results showed that with the change in the woven structure, the fibre volume fraction, resin-rich area etc. seem to change . this adversely affects the performance of the laminates.

Monahan[6] examined the effect of square cut-outs on mode shapes and natural frequencies of clamped isotropic plate both analytically and experimentally . He used finite element model to determine the frequencies and then verify those using holographic analysis

Rajamani and Prabhakaran[7] were one of the first to carry out substantial work in the field of composite plates with cut outs . They studied the effect of square cut-outs on the natural frequencies of simply supported flat symmetric laminated composite plates analytically. They formulated the free and forced dynamic response of the plates considering the effect of cut-outs as a case of equivalent external loading. Laminations were assumed to be symmetric about the mid-plane and the plates were considered to be homogeneous anisotropic plates. Based on the accuracy required a favourable size of the system of frequency was adopted and the results were obtained. Only simple supported and central cut-outs were studied under this paper.

Walley [8] performed similar work on cut-outs but has used a different program STAGSC and holographic analysis. He examined interior cut-outs of sizes 2in x 2in , 2in x 4in and 4in x 4in and the tendency for mode shapes to switch for large cut-outs. Jenq, Hwang and Yang[9] in the year 1993 published their work which basically is another study relating the effect of cut-outs on the natural vibrational characteristics of composite plates. They have used S-glass fibre and epoxy plates for the experiments. Only cantilever condition was adopted for all the tests and parameters such as no of layers removed, distance from support, thickness of plate were modified to get variations in the natural frequency and mode shapes of the composite plates. Holographic method and piezoelectric sensors were used to record the response of the plates under vibration.

Shivakumar and Iyenger [10] studied the free vibration of composite laminates for oscillations with large amplitudes with cut-outs. The work carried out was basically theoretical involving no theoretical works. Ritz finite element model using a 9 noded quadrilateral isoperimetric element was used to determine the dynamic behaviour. The 9 noded elemnt was used to determine the transverse and shear stress. Various size, shape and aspect ratio of cut outs have been used to formulate the behaviour of plates using the above theory.

Namita Nanda[11] basically worked on the amplitude of flexural vibration in case of doubly curved shallow shells having cut-outs. Yazici [12] investigated the effect of cut-outs on the buckling behaviour composite laminate plates. He mostly considered parameters such as cutout size , cutout orientation and corner fillet radius to establish his results. Finite element analyses were also done to verify the experimental results. Some overall important findings of these studies are that the critical buckling loads are not changed by increasing cut-out orientation angle and hole corner fillet radius. The maximum variation was obtained as 5.91% by increasing the hole orientation angle in the buckling loads.

Hasan Al Qablan [13] worked on the bucking aspect of composite plate bearing circular cut-out. The cut-outs are subjected to in plane shear. Various types of in plane loading case were considered. Parameters such as cut-out size, location, fibre orientation were checked. Niranjan Kumar [14] studied the behaviour of laminated composite skew plate with elliptical hole subjected to transverse loading. Janghorban and Rostamsowlat [15] studied the effect of both circular as well as non-circular cut-outs on the vibrational characteristics of composite plates.

SCOPE OF THE PROPOSED WORK:-

From the above review of literature of various researchers around the world it is evident that the studies of the various static and dynamic characteristics of the composite plates have been an active field or research since a long time. Works covering the strength, vibrational characteristics and buckling phenomenon have been done by many people and is still going on. Composite has been an active area of research as slowly the use of composite is increasing in various areas.

It can be noted from the above studies that most of the work done on composite laminates is mostly analytical. Finite element model has been used in such case using various elements to design the composite and find its characteristics values. Not much work have done on the experimental aspects . but slowly with the advent of modern technology in the form of exciting instruments such as modal hammers and sensing instruments such as accelerometer it is being possible to detect and measure the vibrational characteristics of the composites .Moreover almost all works have generally used unidirectional fibres for the fabrication of composites. But these days woven fibres are more in use in laminates.

These days where ever composite plates are used they are subjected to various types of cut-outs for various practical uses such as providing vents for passing electrical wires, to provide openings for doors and windows, to efficiently reduce the weight and the cost etc. so a more detailed study is required for determining the vibrational aspects of the composite plates with cut-outs.

Keeping the above facts in view the scope of the above study is to:-

- Determine the natural frequencies and mode shapes of the composite laminates using experimental modal analysis.
- **Ansys** modelling of the composite laminates to find the vibrational characteristics.
- Comparison between the data obtained from the experimental analysis and Ansys modelling and studies the variation.
- Extension of the experiments involving cut-out in the plates.
- The study of effect of cut-outs is to be done in the following cases
    - Effect of change in size of cut-out with thickness of plate remaining same.
    - Effect of change in aspect ratio of the cut-out.
    - Effect of change in thickness of plate with cut-out size remaining same.
    - Effect of the relative position of the cut-out.
    - Effect of change in distance of the cut-out from end support.

.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 GENERAL OVERVIEW

Experimental modal analysis in its simple terms is known as the process whereby we can describe a structure in terms of its natural characteristics such as :

- Frequency
- Damping
- Mode shapes

Using modal analysis we can obtain various dynamic properties of the structure. Basically there are 3 important tools which we will mainly deal with during modal analysis. These are

- Frequency response function
- Auto spectrum
- Coherence

Frequency Response Function

FRF is particular tool used for the determination of natural frequencies of the excited structure. It is basically a transfer function which transfers the signals from time domain to frequency domain. Suppose we apply a constant force to a plate specimen connected with an accelerometer with a fixed frequency of vibration but in a sinusoidal fashion. If we measure the time response we will find that the amplitude changes as we change the rate of oscillation of input force as shown in the figure.

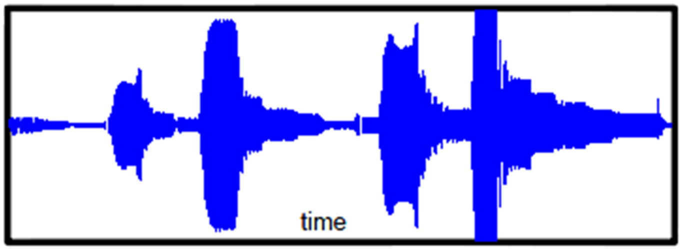

Figure 3.1: Time response function.

Now the above time data is obtained because the rate of oscillation is closer to the natural frequency of the plate. The above data when converted using Fast Fourier Transform in to the frequency domain gives the desired FRF.

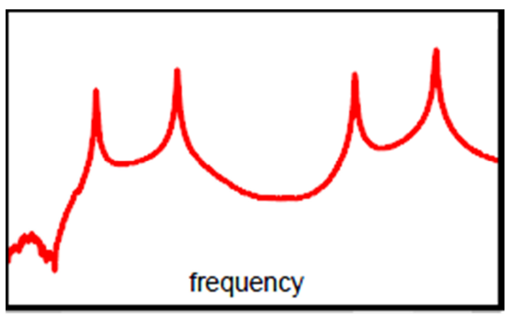

Figure 3.2 : Frequency Response Function.

From the FRF we can deduce that peaks occur in these functions at the resonant frequencies of the system. Also these peaks occur at frequencies when amplitude is maximum.

Auto spectrum:

Coherence:

3.2 FABRICATION TECHNIQUE OF COMPOSITE LAMINATE:

To meet the large scale needs of the industry for composites, the industry has evolved over a dozen separate fabrication processes as well as a number of hybrid processes. Each of the above processes has their own advantages and disadvantages. They are mostly application specific. Hand lay-up and Spray lay-up are the two most simple and oldest techniques for composite fabrication. Among the two **Hand lay-up** is the most labour specific and the crude method.

In hand lay- up the materials used are :

1. E-glass woven roving as reinforcement
2. Epoxy as resin
3. Hardener as catalyst
4. Polyvinyl alcohol as a releasing agent

The method adopted for the casting of the composite plates is as follows. First the glass fibre roll is cut into squares of 30 cm x 30 cm. Then according to the number of layers of composite plate to be made, that many number of fibre sheets are weighed. The epoxy is taken in 1:1 ratio as that of the woven glass fibre sheets. To the epoxy 10% of the hardener is added and mixed thoroughly.

On clean and smooth plywood a polythene sheet was laid and the spray of the releasing agent was applied on it. Then a layer of epoxy is applied on the sheet. Over it the glass fibre is laid and thoroughly pressed by the application of roller. Again a layer of epoxy is applied along with a sheet of glass fibre over it and rolled. This process is continued for all the layers. This whole arrangement is kept for 24 hours for hardening and after that it is cut it desired size of 23.5 x 23.5 cm using marble cutter. This plate is then subsequently used for testing.

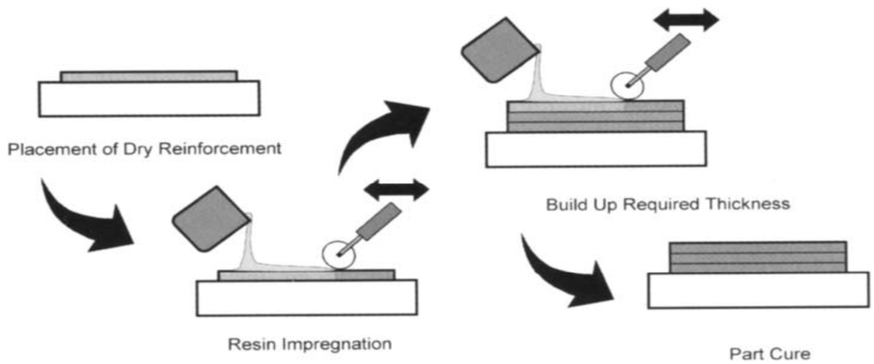

Figure 3.3: Hand Lay-up process

Many a time a mould is also used in hand lay-up method. It is generally used whenever the composite is not directly joined with the structure. Moulds come in various shape, sizes starting from a flat sheet to having infinite curves and corners. Before fabrication the mould is first prepared with the application of releasing agent so that after hardening the composite does not sticks to the mould. Then reinforcements are cut and laid in the mould as per requirements. Then resin is catalysed and added to the fibre. A brush or roller is used to perfectly compact the layers and squeeze out excess resin.

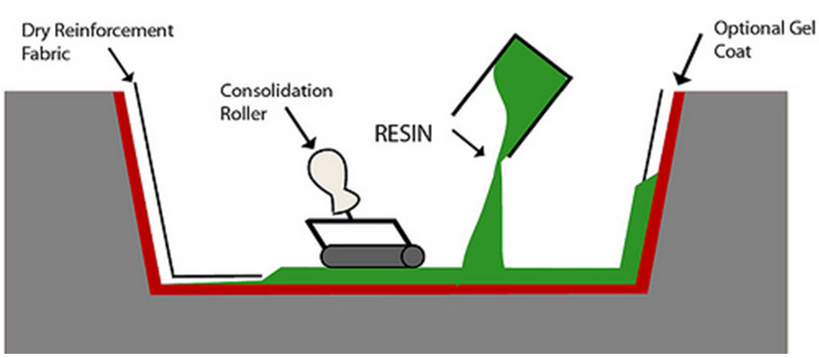

Figure 3.4 Industrial Hand lay up process in a mould

This process has some advantages such as:

- Less investment
- Simple fabrication process
- Possible at room temperature

The disadvantages of this process include

- Uniform laminates are difficult to be produced
- The resins used can sometimes have adverse on the skin of the fabricator.

3.3 EXPERIMENTAL SETUP:-

The experimental set up used by us in the laboratory was a frame which has all the utilities for providing cantilever, simply supported and fixed end conditions to the plates for testing. The components used for modal testing are :-

Accelerometer Brüel&Kjær (4507):-

The Accelerometer is a device used for the sensing the vibration from the plates after the excitation has been made on it. The type 4507 accelerometer consist of a Thetashear accelerometer and a Deltatron preamplifier in a light titanium casing.

Its main features are

- Durable titanium casing
- Variable mounting clips available for different samples
- Light weight
- High sensitivity
- Can be mounted in tri axial way .

- Use very low power

It can be put to various types of uses such as

- Measuring the modal parameters of samples
- Several types of frequency measurments.
- Multichannel analysis is possible

This accelerometer is fixed to the composite laminate using glue before the start of the experiment.

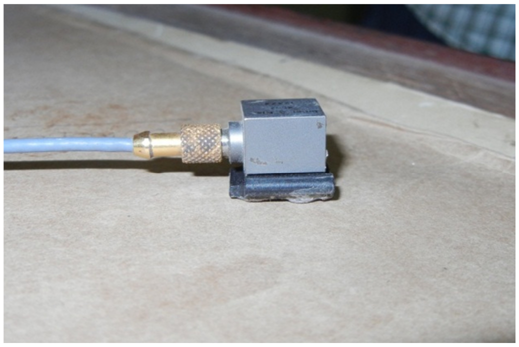

Figure 3.5: Accelerometer Brüel&Kjær (4507)

Modal hammer Brüel&Kjær (2302-5)

Modal hammer are also known as Impact hammers. Their prime function is to provide a calculated amount of excitation to the structure. The type of structure varies from small to medium sizes. The accelerometer then picks up the response of the structure and sends it back to the FFT analyser. We can apply a perfect excitation to the plate without adding any extra mass to the structure.

The sensitivity of the impact is measured with the help of built in sensors inside the hammer. It also has some built in mechanism to remove unwanted noise from outward source. The result is thus a clean and smooth output signal. The variable tips of the impact hammers can be changed based upon the type of structure. This determines the amplitude and band width of excitation.

Features:-

- The range of sensitivity is quite large.
- A comfortable handle
- No change in the dynamic properties of structure
- Comes with replaceable tips

Uses:

- Impact force can be measured
- Can be used for modal analysis
- Measure wide range of structural response

Figure 3.6: Modal hammer Brüel&Kjær (2302-5)

Brüel & Kjær FFT Analyser :

FFt Analyser main purpose is to receive a time varying signal from the accelerometer and convert it into a frequency based signal or FRF. It uses basic Fourier theorem to make these transforms. If the signal in the time domain is periodic then in the frequency domain the signal is dominated by a single frequency component. The

FFT analyzer is connected to a computer platform where using the pulse labshop we can view the FRF in real time .n a FFT Analyzer first the input signal is digitized. Then using Nyquist theorem the sampling rate and the frequency components are compared.

Figure 3.7 : FFT Analyzer

Figure 3.8: Connections of Modal Hammer and Accelerometer with the FFt Analyser

Brüel & Kjær Pulse labshop :-

Pulse lab shop is the platform used in the computer to investigate the data from the FFT Analyzer and produce the required frequency response. It was developed by Bruel & kjaer and is high end analyzer software. It has wide range of applications in static and dynamic analysis of structures. One of the great feature of pulse is that real time analysis and results can be obtained from this. Thus we can use it in field and verify the results immediately.

The various things which we can measure using the Pulse are :

- Frequency Response Function
- Coherence
- Time weighting signals

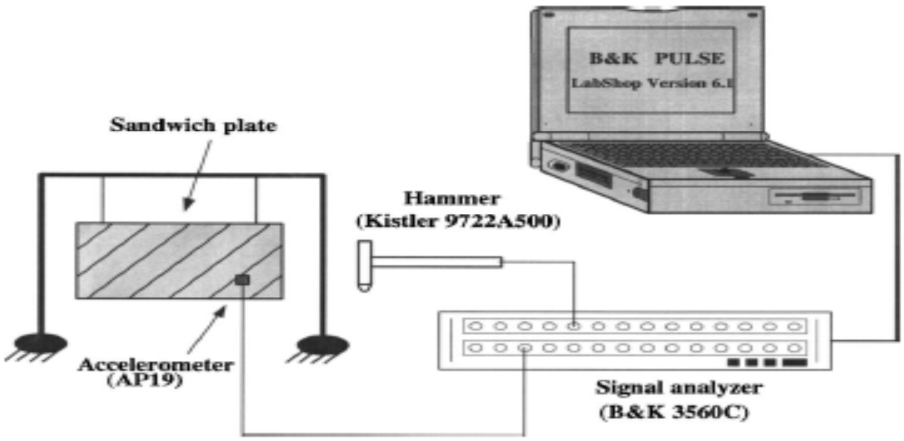

Figure 3.9 : Experimental setup

3.4 EXPERIMENTAL PROCEDURE:

- The composite plate was fixed in the frame as per the required end conditions.
- The accelerometer was fixed to the plate by both side tapes to the plate.
- The impact hammer was kept ready for excitation.
- In the same time the accelerometers and hammer must be connected to the FFT Analyser as shown in the setup.
- Pulse lab shop was run in a computer connected to the FFt Analyser and the template was created to measure the frequency response.
- Then the plate was excited using the impact hammer .
- The response was detected and the FRF was obtained on the PULSE.

Figure 3.10 : Frame used for the modal testing of composite plates .

Figure 3.11 : Fabrication Setup .

CHAPTER 4

MATHEMATICAL MODELLING

Finite element modelling has evolved as a very powerful tool in solving many real life engineering problems. FEM now-a-days is used in computing all types of elastic-plastic, residual, thermal, electromagnetic, buckling and thermal analysis. The prime objective of finite element modelling is to represent the behaviour of physical structure being analysed. However it is the modelling techniques and assumptions used in analysis which decide the accuracy of results. ANSYS is a FEM program that is used here to analyse the vibration characteristics of the plates.

In analysing the composite plates SHELL 99 element is used to model the different layers of Epoxy Glass fibres in ANSYS 10.0. Shell 99 is basically used for layered structured models. SHELL 99 allows modelling up to 250 layers.

The element has 6 degrees of freedom at each node i.e. 3 translational in X-, Y-, Z- and three rotational freedoms in X-, Y-, Z- directions

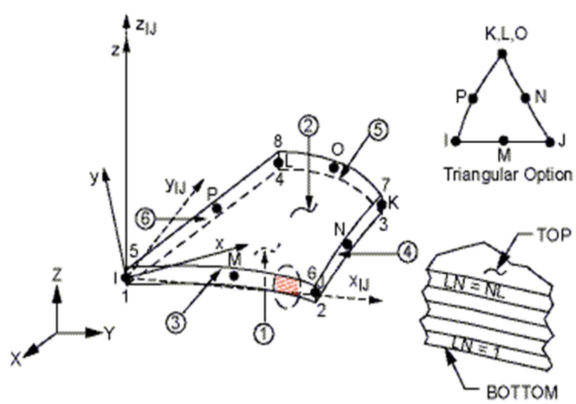

Fig 4.1: Element of Shell 99.

Other material properties of E Glass Fibres used during modelling are given in the table below:

Table 4.1 : Material properties of E Glass fibres

Element	Elasticity	Poisson Ratio	Density
Shell 99	2.8E10 Gpa	0.33	2160 kg/cm^2

Initially the whole plate is modelled using SHELL 99 element and the required no. of layers are provided. After modelling the structure is meshed. Each model has been meshed using free 3-D Tri mesher. Edge length during meshing is kept 4 units to avoid generation of too many cells which can lead to long solver runs.

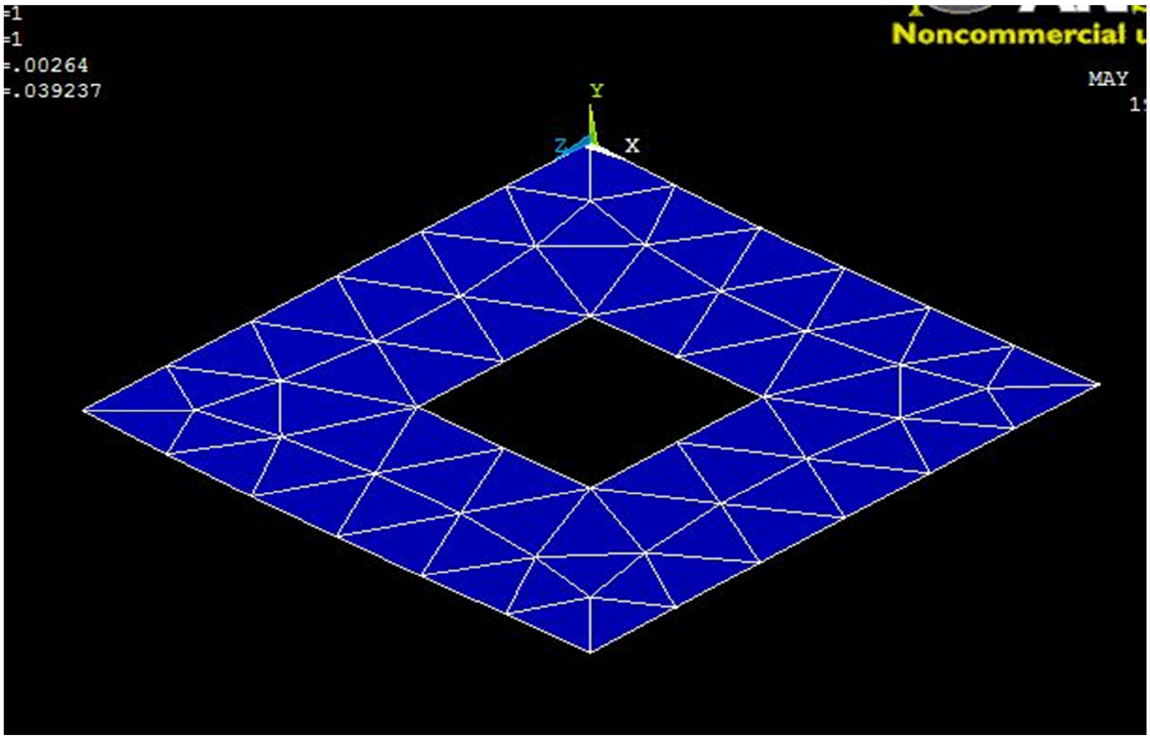

Fig 4.2: Meshing of an 8cm * 8cm cut-out plate.

LOADS AND BOUNDARY CONDITIONS:

Boundary conditions are applied as per the experimental setup including cantilever, fixed and simply supported. Following table depicts the constraints used in different boundary conditions.

Table 4.2 : Constraints for various boundary conditions used.

	UX	UY	UZ	ROTX	ROTY	ROTZ
Cantilever	Constrained	Constrained	Constrained	Constrained	Constrained	Constrained
Fixed	Constrained	Constrained	Constrained	Constrained	Constrained	Constrained
Simply Supported	Constrained	Constrained	Constrained	Free	Free	Free

SOLUTION:

To perform the modal analysis of the models created BLOCK LANCZOS method is used. This solver is a very accurate method and works well for shells or a combination of shells and solids. The Block Lanczos method uses the sparx matrix solver. The memory required is minimum and modes more than 40+ can be found out using this method. Following data are used in Block Lanczos method during Ansys modeling of epoxy glass fibre composite plates:

Table 4.3: Data for Block Lanczos Method of modal analysis.

No. of modes to extract	Expand Mode Shapes	Frequency Range
4	Yes	0-1600 Hz

The solver is then executed and the modal frequencies values generated are read from Post-Processing window. For each modal frequency deformed shape of the model can also be recorded.

CHAPTER 5

RESULTS AND DISCUSSIONS

First a study was done on the modal frequencies of a aluminium bar in a free free condition in the methodology as explained in chapter 3 of this thesis. The results obtained are shown in table 5.1 and 5.2 respectively.

Table 5.1.: Modal Frequencies of Aluminium bar from experiment.

Frequency	Theoretical	Experimental		
1st Mode	410	384	384	384
2nd Mode	1123	1080	1084	1084
3rd Mode	2203	1980	2000	1976

Table 5.2: Modal Frequencies of Aluminium bar from Ansys modelling

```
*****  INDEX OF DATA SETS ON RESULTS FILE  *****

 SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
   1  410.13            1          1         1
   2  1128.5            1          2         2
   3  2207.2            1          3         3
   4  3638.2            1          4         4
```

5.2 Modal Testing of Composite laminates without cut-out:

Table 5.3: Modal Frequencies of 8 layer Composite Laminates for different end conditions.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	136	132	132	132	89	92	84	88	120	112	116	112
Mode 2	220	212	212	212	237	232	228	228	224	228	228	228
Mode 3	320	356	356	352	448	428	424	428	511	484	480	488
Mode 4	585	540	536	536	683	664	652	664	793	764	760	772

Table 5.4: Modal Frequencies of 12 layer Composite Laminates for different end conditions.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	20.67	20	20	20	125.6	124	124	124	163.53	164	160	164
Mode 2	320.56	320	324	320	215.72	212	212	212	279.65	280	280	276
Mode 3	497.67	496	496	496	638.13	636	632	636	427.5	428	420	424
Mode 4	845.3	**840**	**840**	**846**	**845.88**	**840**	**842**	**840**	**718.54**	**712**	**716**	**740**

Table 5.5: Modal Frequencies of 16 layer Composite Laminates for different end conditions.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	44.87	44	44	44	146.34	144	144	148	255.67	256	256	256
Mode 2	329.76	328	328	328	393.34	392	392	392	329.57	328	328	328
Mode 3	466.76	464	464	464	725.44	716	720	732	458.54	456	456	452
Mode 4	816.763	812	808	816	1063.21	1052	1060	1068	505.43	500	500	504

5.3 Modal Testing of Composite plates with cut-out

Case 1: <u>Effect of change in size of cut out:</u>

In this case we study the variation in the modal frequencies of the plates by varying the size of the cut-out provided in the plate at its centre. All the cut-outs provided are square cut-out. The size is varied from 36 cm^2 to 100 cm^2. All the support conditions are tested and tabulated in table 5.6, 5.7 & 5.8.

Table 5.6: Modal Frequencies of 8 layer Composite Laminates with 25.5% central cut-out.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	20.45	20	20	20	89.4	90	88	88	125.34	124	132	128
Mode 2	198.34	200	196	196	213.75	212	212	212	214.79	212	212	212
Mode 3	374.45	372	372	372	447.56	448	440	442	334.45	332	332	332
Mode 4	546.22	554	544	552	556.54	550	552	563	435.5	432	436	436

Table 5.7: Modal Frequencies of 8 layer Composite Laminates with 34% central cut-out.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	26.21	24	28	20	73.2	72	72	76	126.4	124	128	128
Mode 2	193.28	192	192	196	223.2	200	220	220	195.32	191	194	196
Mode 3	218.58	216	216	220	450.32	452	476	448	266.75	272	268	265
Mode 4	389.31	388	392	388	700.21	716	710	692	433.2	476	428	436

Table 5.8: Modal Frequencies of 8 layer Composite Laminates with 42.5% central cut-out.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	26.21	101	98	103	67.4	68	64	68	265.2	264	266	264
Mode 2	193.28	184	185	185	158.79	160	156	160	443.4	440	442	442
Mode 3	218.58	202	205	201	292.51	288	296	298	547.19	548	546	546
Mode 4	389.31	456	403	430	325.43	324	392	331	694.57	691	692	692

From the results obtained above graphs were plotted between frequency and area of cut-out for each support conditions and are shown in figure 5.1,5.2 & 5.3. In case of cantilever (fig: 5.1) and simply supported (fig:5.3.) there is a substantial decrease in the frequency with the increase in area of cut-out. The decrease is about 43% for mode 3, 12% for mode 2 & 25% for mode 1 for cantilever case. But in case of fixed end condition there is initial decrease in frequency with increase in cut-out till cut-out area of $64 cm^2$. After that it shows an increasing pattern (fig:5.2)

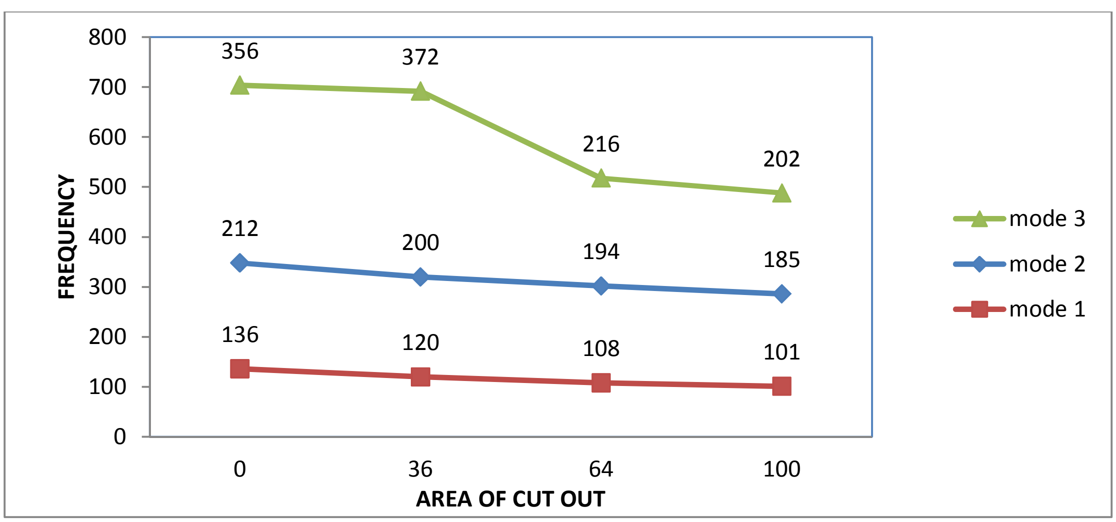

Figure 5.1: Variation between modal frequencies with change in size of cut-out for cantilever end condition.

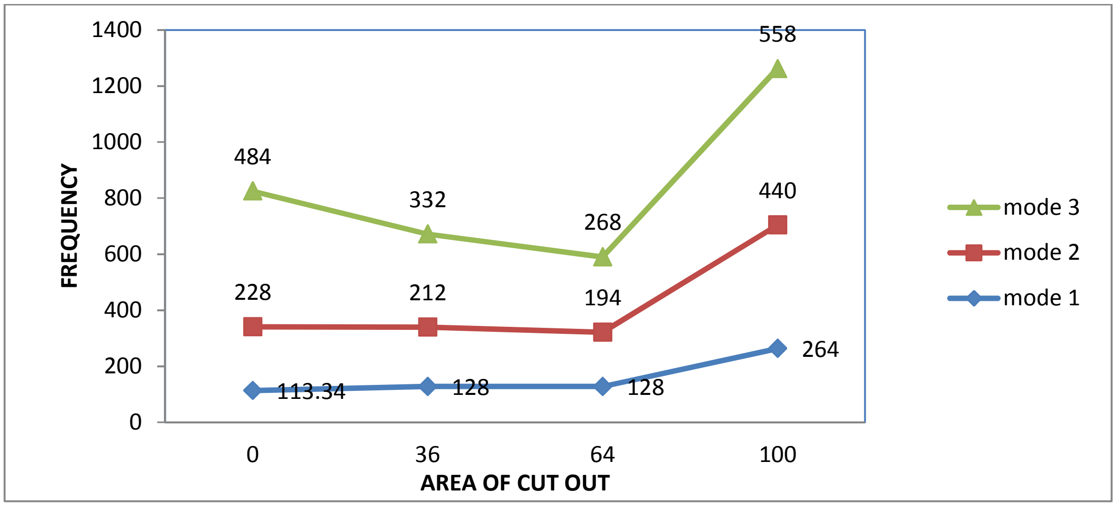

Figure 5.2: Variation between modal frequencies with change in size of cut-out for fixed end condition.

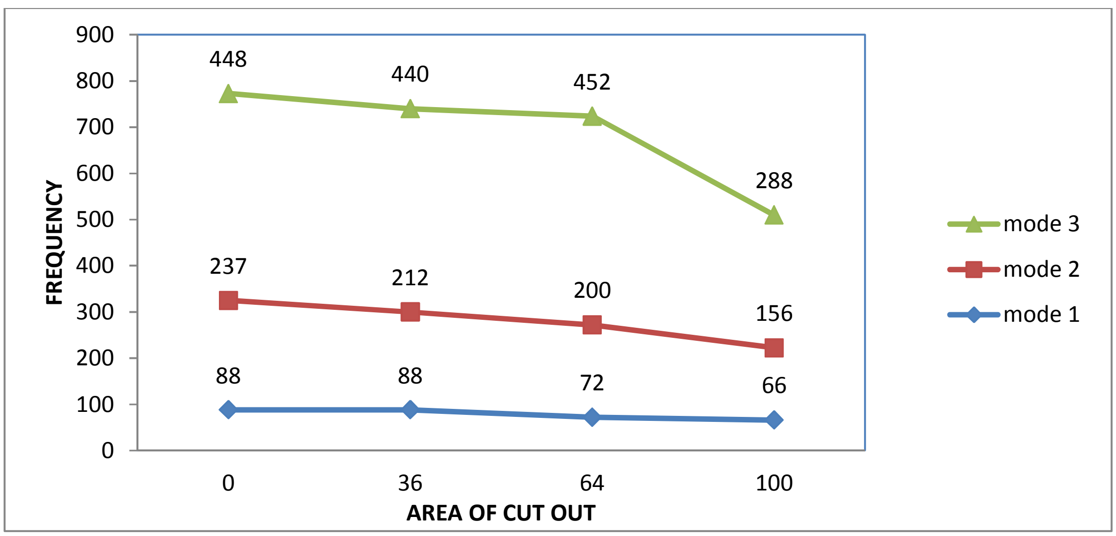

Figure 5.3: Variation between modal frequencies with change in size of cut-out for simply supported end condition.

Case 2: <u>Effect of change in aspect ratio of cut out:</u>

In this case we studied how frequencies changes as we vary the aspect ratio of the cut-out. The area of the cut-out was kept constant. All the cut-outs were centrally located and 8 layer plates were used. The results obtained were shown in tables 5.9 & 5.10. Then a relative graph was plotted between frequency and aspect ratio 1, 2 & 3. These are shown in fig 5.4, 5.5 & 5.6.

Table 5.9: Modal Frequencies of 8 layer Composite Laminates with a central cut-out of Aspect Ratio of 2.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	17.23	20	16	16	96.54	92	100	100	152	152	144	152
Mode 2	126.74	128	124	128	237.67	236	308	240	329.4	328	328	332
Mode 3	178.82	180	176	180	401.21	396	428	404	643.22	640	640	644
Mode 4	598.65	448	492	436	603.22	600	600	568	746.58	744	744	744

Table 5.10: Modal Frequencies of 8 layer Composite Laminates with a central cut-out of Aspect Ratio of 3.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	25.54	20	28	24	65.64	64	72	68	149.8	148	152	152
Mode 2	156.43	152	158	156	173.21	172	184	172	277.66	276	340	276
Mode 3	477.32	488	476	476	277.79	280	352	276	692.34	688	700	740
Mode 4	618.32	620	618	620	790.85	360	468	360	830.43	832	828	828

The variation of frequency with change in cut-out was plotted for each support conditions. It was observed from fig 5.4 that in case of cantilever end conditions at higher there is a large percentage increase in frequency of about 25.44%. But at lower modes this change is very less. In case of fixed end condition there is a decrease in frequency of about 25 to 32% for mode 2 and mode 3 on changing aspect ratio from 2 to 3 as shown in fig.5.5.

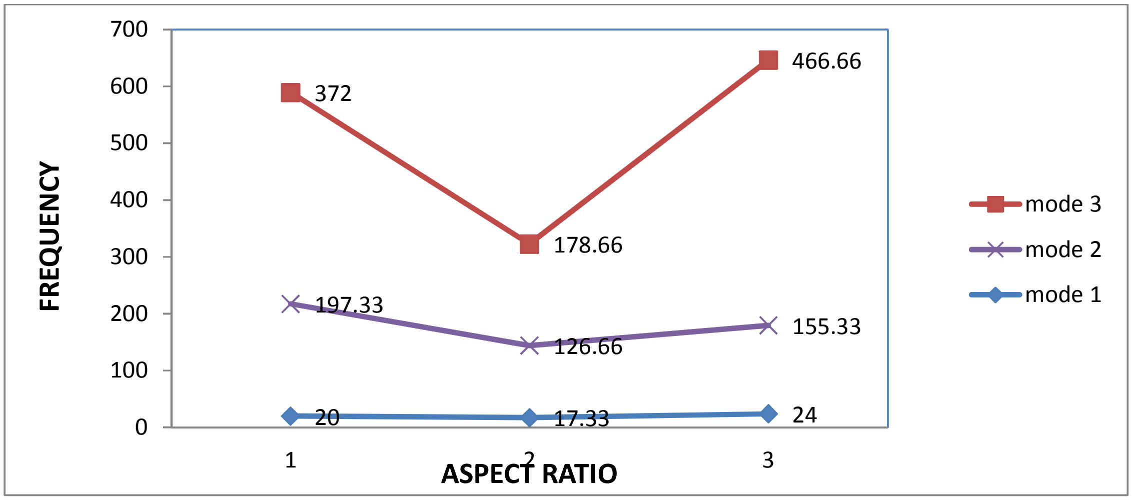

Figure 5.4: Variation between modal frequencies with change in aspect ratio for cantilever end condition.

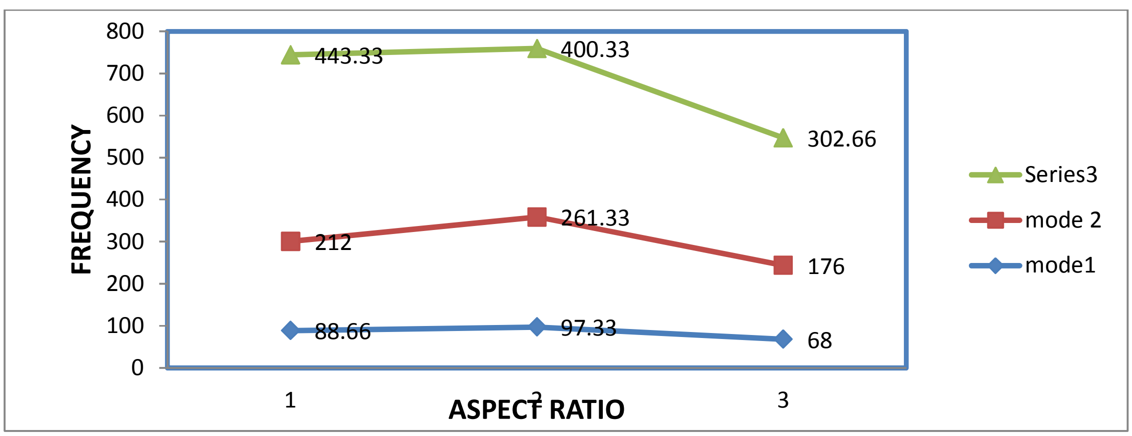

Figure 5.5: Variation between modal frequencies with change in aspect ratio for simply supported end condition.

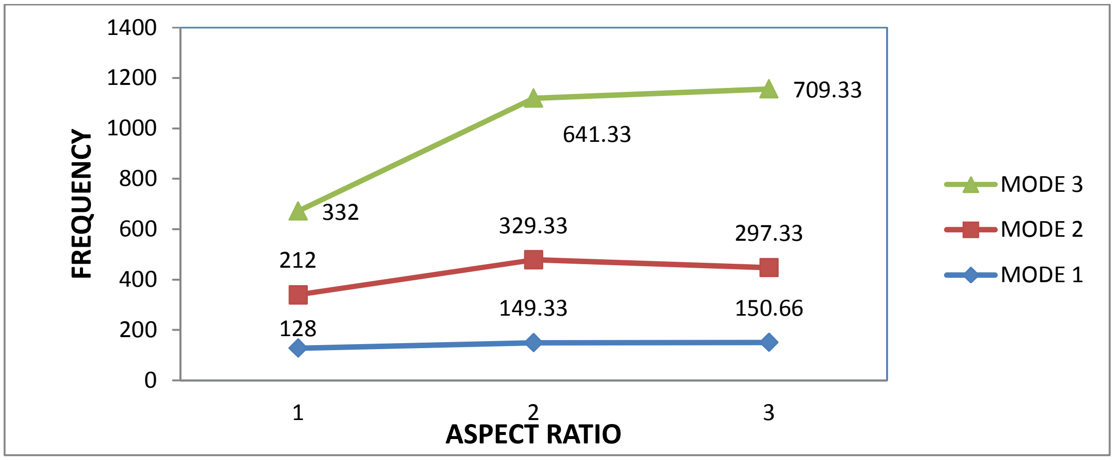

Figure 5.6: Variation between modal frequencies with change in aspect ratio for fixed end condition.

Case 3: Effect of change in layers of composite plate with same size of cut out:

In this case we changed the thickness of the composite plates keeping all parameters same. All the support conditions were checked. We varied the thickness from 8 layer to 12 layer and then to 16 layer. The Cut-out of 25.5% was located at the centre. The results are shown in tables 5.11&5.12

Table 5.11: Modal Frequencies of 12 layer Composite Laminates with a central cut-out of 25.5%.

	Cantilever				**Simply Supported**				**Fixed**			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	24.66	24	24	20	24.75	24	24	24	184.43	180	180	192
Mode 2	309.97	308	308	316	204.66	152	288	204	401.23	400	404	396
Mode 3	643.56	640	644	644	598.65	512	596	596	523.23	520	520	516
Mode 4	1110.54	1444	1004	946	720.5	724	716	716	746.22	744	744	780

Table 5.12: Modal Frequencies of 16 layer Composite Laminates with a central cut-out of 25.5%.

	Cantilever				Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental			Ansys	Experimental		
Mode 1	23.32	24	24	20	201.27	204	200	200	297.56	288	296	304
Mode 2	442.23	440	436	440	446.87	448	444	448	442.99	440	444	444
Mode 3	790.92	788	792	788	615.53	612	612	616	684.46	684	688	684
Mode 4	880.44	884	884	872	1022.78	1024	832	1020	888.65	888	884	828

In this case comparison plots were made between frequency and no of layers of the cut-out. In case of cantilever support conditions, there is significant increase in frequency by around 122% for mode 2 and 112% for mode 3. It can be observed from the graph in fig 5.7. One of the remarkable points is that the rate of increase in frequency in case of simply supported condition increases with increase in layers.

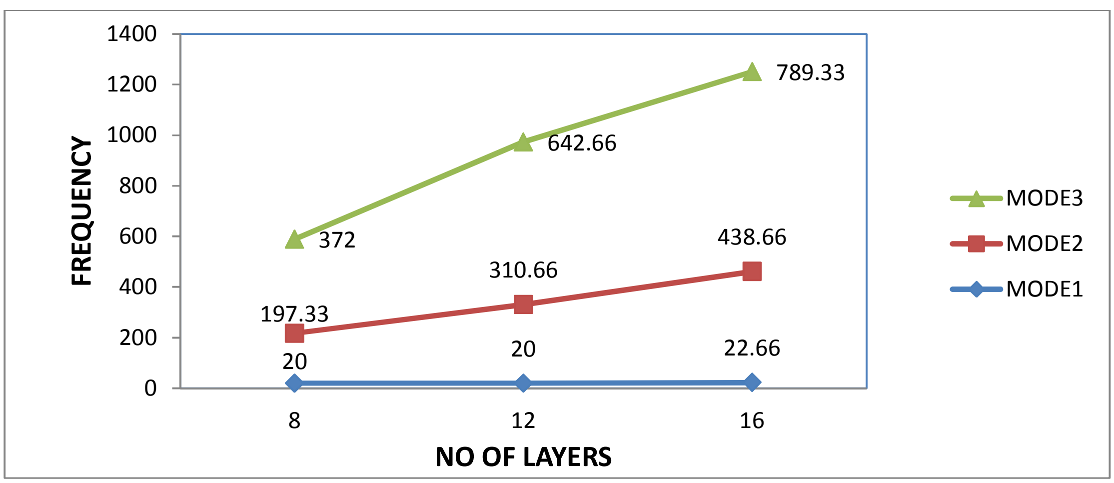

Figure 5.7: Variation between modal frequencies with change in no. of layers for cantilever end condition.

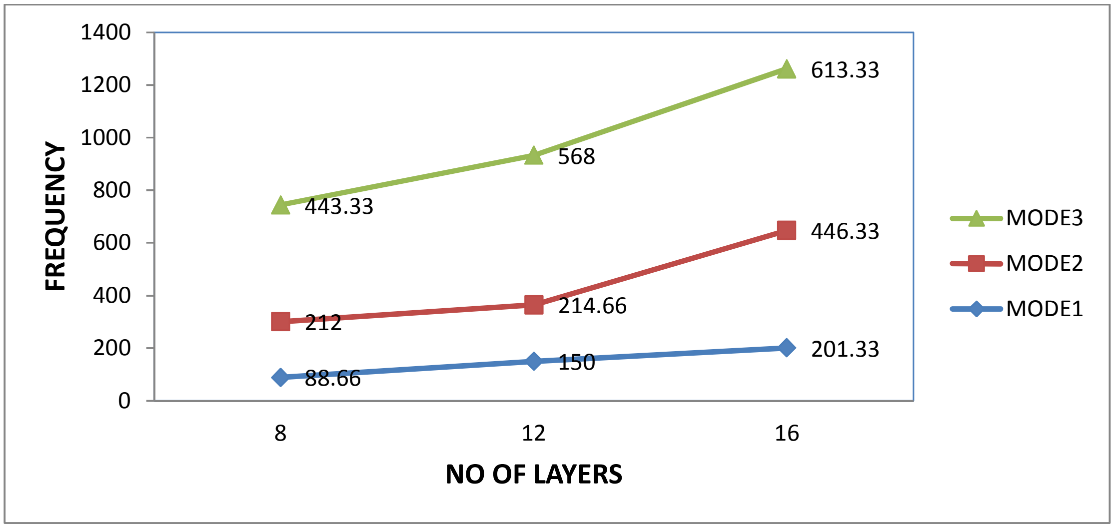

Figure 5.8: Variation between modal frequencies with change in no. of layers for simply supported end condition.

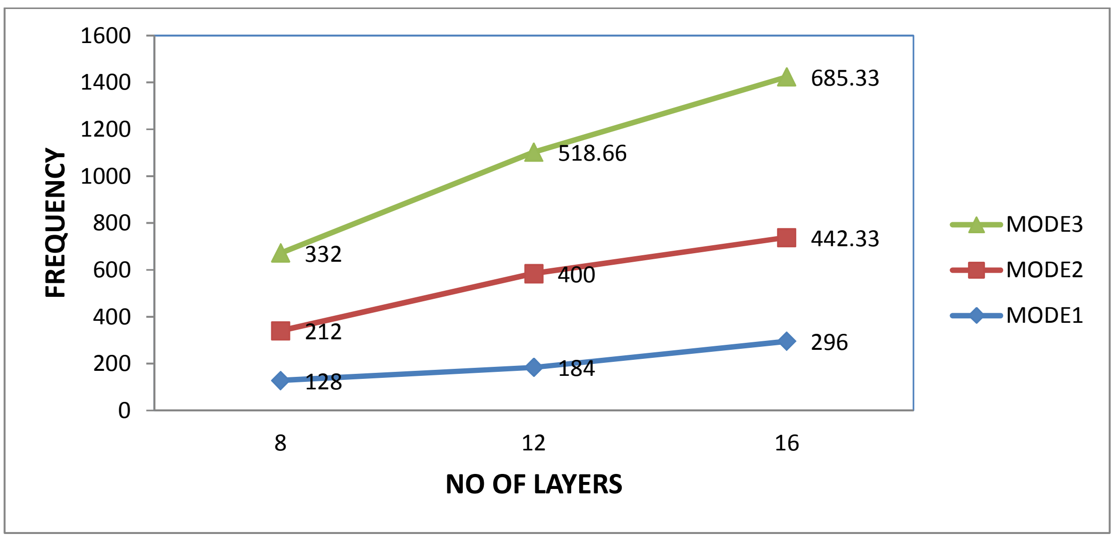

Figure 5.9: Variation between modal frequencies with change in no. of layers for fixed end condition.

Case 4: <u>Effect of change in position of cut-out on composite plate</u>:

In this case we study the variation in the frequency on the composite laminates if we change the position of the cut-out. In the first case it was located at the centre. Then it was moved to the side. And at last it was moved to a corner. Thus effectively the cut-out distance from the centre increases. In this case only 8 layer plates are used.

Table 5.13: Modal Frequencies of 8 layer Laminates with a corner cut-out of 25.5%.

	Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental		
Mode 1	41.66	40	40	40	167.5	164	168	164
Mode 2	342.56	356	324	366	374	372	436	580
Mode 3	533.2	534	520	520	678.55	696	676	836
Mode 4	742	730	728	728	1002.33	824	1044	1172

Table 5.14: Modal Frequencies of 8 layer Composite Laminates with a side cut-out of 25.5%.

	Simply Supported				Fixed			
Frequency	Ansys	Experimental			Ansys	Experimental		
Mode 1	62.33	60	60	64	156.2	156	156	156
Mode 2	274.55	272	276	276	408.33	400	400	404
Mode 3	441	440	436	436	563.5	564	560	560
Mode 4	806.66	804	804	804	1005.66	1020	1008	1020

The relation between frequency and the relative position of the cut-out was plotted. It was observed that in case of simply supported end condition with increase in distance of cut-out from centre, there is a negative change of around 55% in the frequency. But for mode 2 and mode 3 there is positive change of around 60 % for mode 2 and 19% for mode 3(fig: 5.10). But in case of fixed end condition there is fairly an increase in all three investigated mode shapes (fig 5.11).

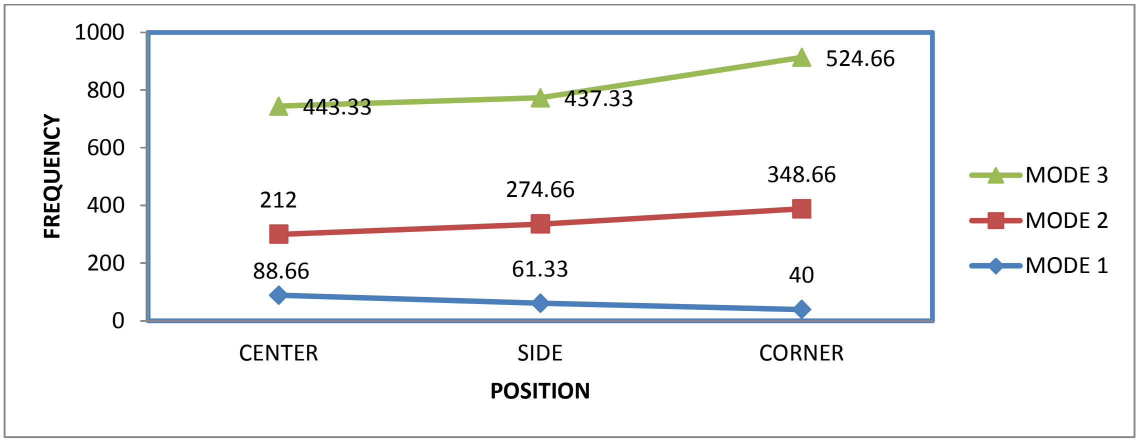

Figure 5.10: Variation between modal frequencies with change in position of cut-out for simply supported end condition.

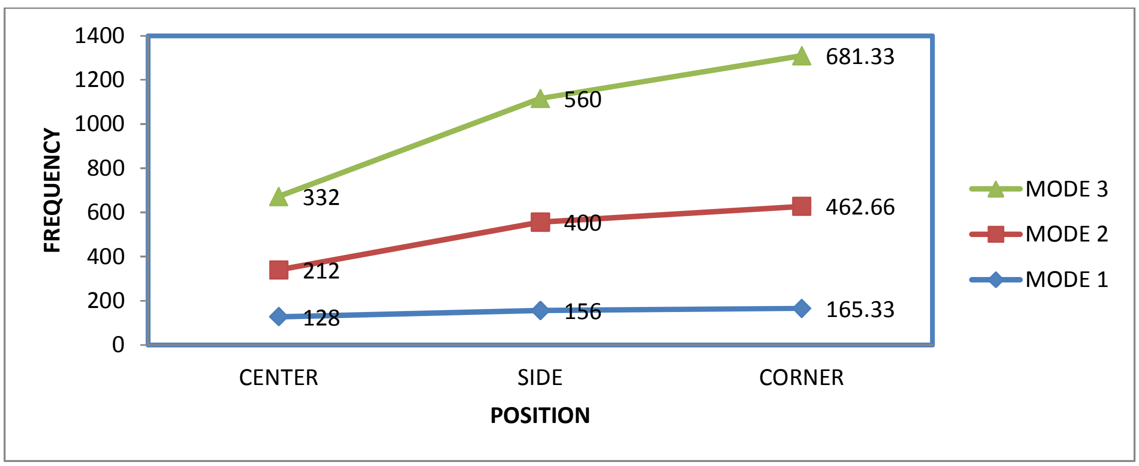

Figure 5.11: Variation between modal frequencies with change in position of cut-out for fixed end condition.

Case 5: <u>Effect of change in distance of cut-out from support on composite plate</u>:

This is the last case we have investigated. In this case we have varied the distance of a 6cm x 6 cm cut-out located on the centre line of the plate from the end support. Only cantilever condition was adopted and three variations were done. First with the cut-out at a distance 6cm from the centre, then in the centre and finally at 18 cm from the centre. The results are shown in table 5.15 & 5.16. the corresponding variation is shown in figure 5.12.

Table 5.15: Modal Frequencies of 8 layer Composite Laminates with a cut-out of 25.5% at a distance of 6 cm from support.

Frequency	Ansys	Experimental		
1st Mode	102.33	102	98	101
2nd Mode	188	186	182	188
3rd Mode	374.45	376	372	370
4th Mode	560.2	544	546	523

Table 5.16: Modal Frequencies of 8 layer Composite Laminates with a cut-out of 25.5% at a distance of 18 cm from support.

Frequency	Ansys	Experimental		
1st Mode	130.8	131	128	135
2nd Mode	234.56	234	232	230
3rd Mode	332.3	326	323	320
4th Mode	502.33	460	468	488

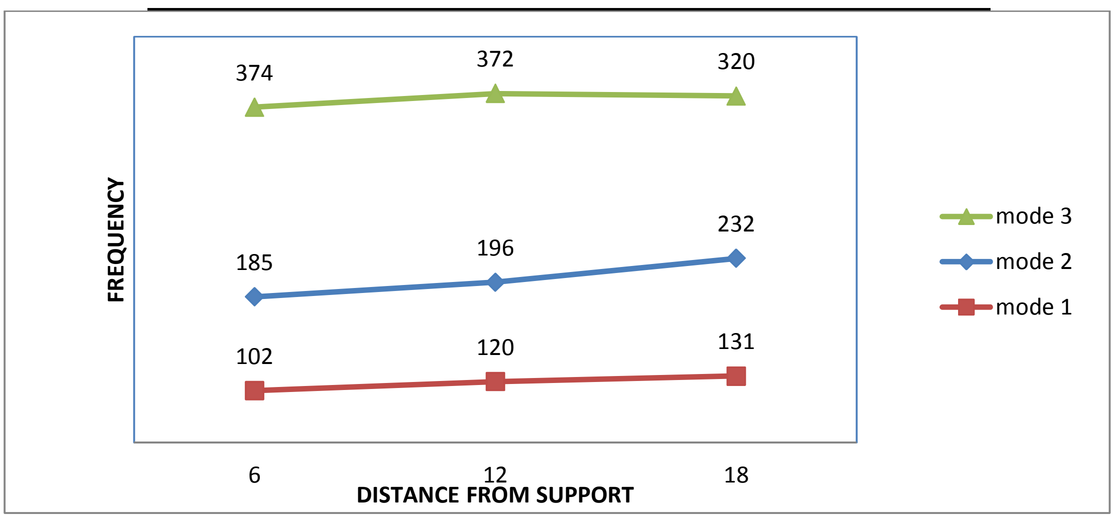

Figure 5.12: Variation between modal frequencies with change in distance cut-out from support for (cantilever end condition).

MODE SHAPES FROM ANSYS:

Effects of cut-out size on mode shapes for fixed condition:

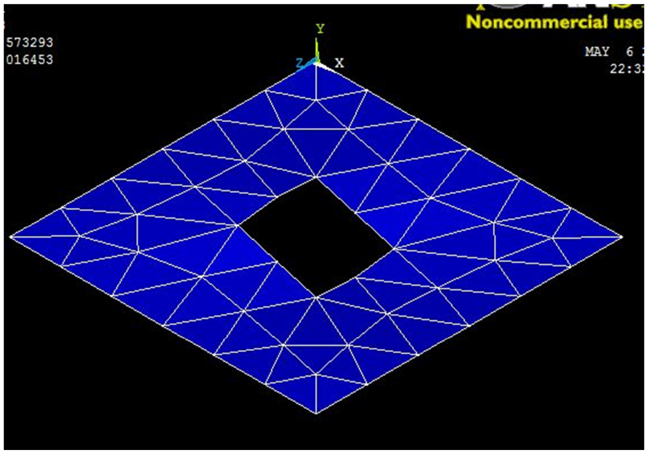

Fig 5.13: Mode shape of composite plate with 25.5% cut-out.

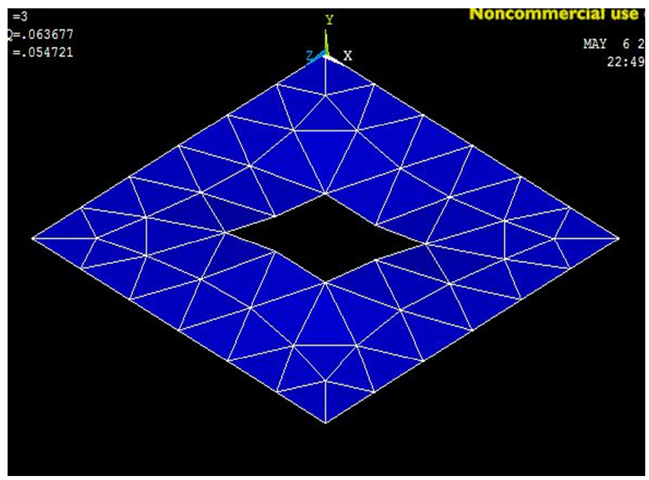

Fig 5.14: Mode shape of composite plate with 34% cut-out.

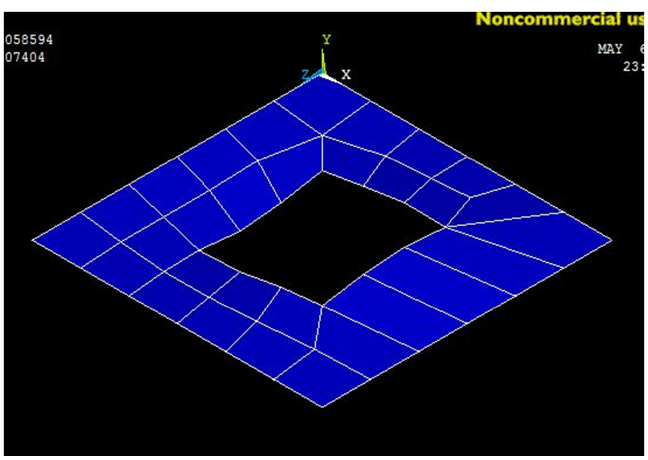

Fig 5.15: Mode shape of composite plate with 42.5% cut-out.

Effect of layers on mode shapes for simply supported condition:

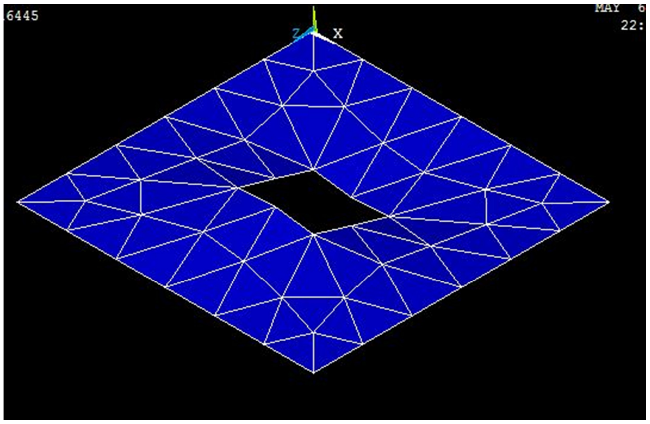

Fig 5.16: Mode shape of 8 layer composite plate with 25.5% cut-out

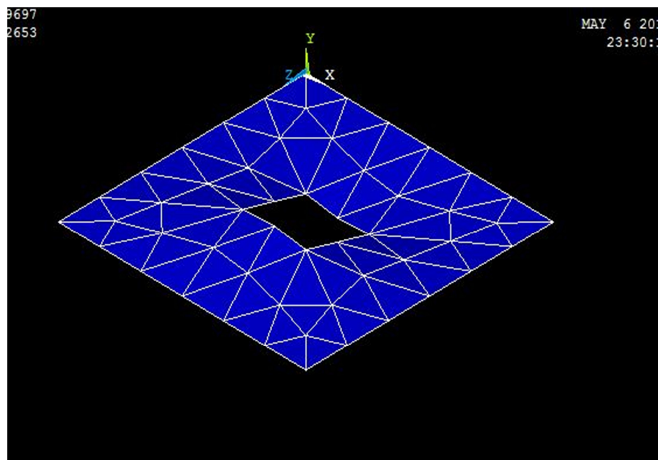

Fig 5.17: Mode shape of 12 layer composite plate with 25% cut-out

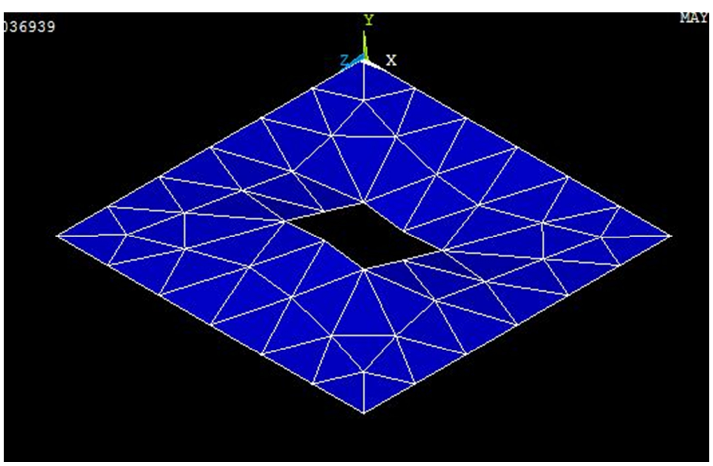

Fig 5.18: Mode shape of 16 layer composite plate with 25.5% cut-out

Effect of AR on mode shapes for fixed condition:

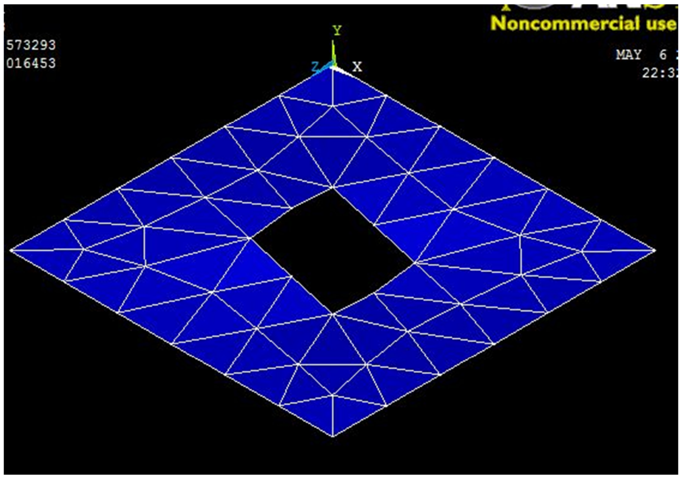

Fig 5.19: Mode shape of composite plate with cut-out of Aspect Ratio 1.

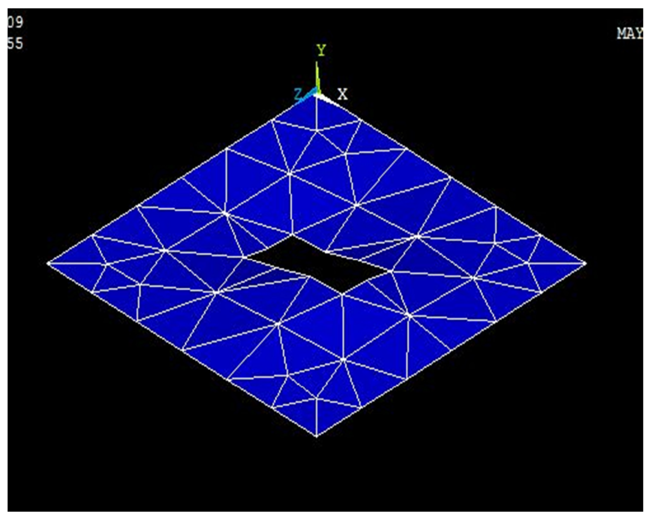

Fig 5.20: Mode shape of composite plate with cut-out of Aspect Ratio 2.

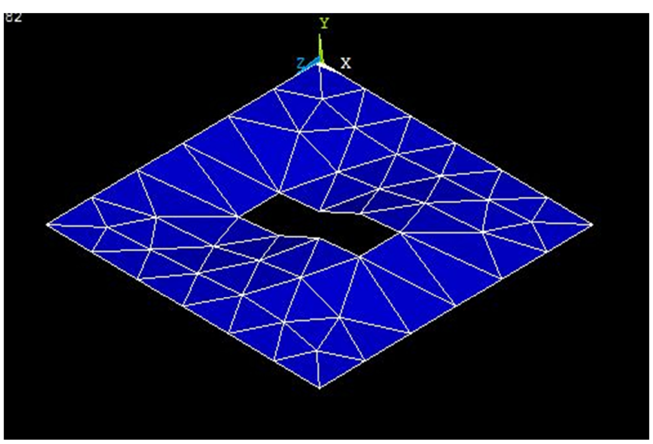

Fig 5.21: Mode shape of composite plate with cut-out of Aspect Ratio 3.

Effect of support conditions on 8 layer composite plate with 25.5% cut-out:

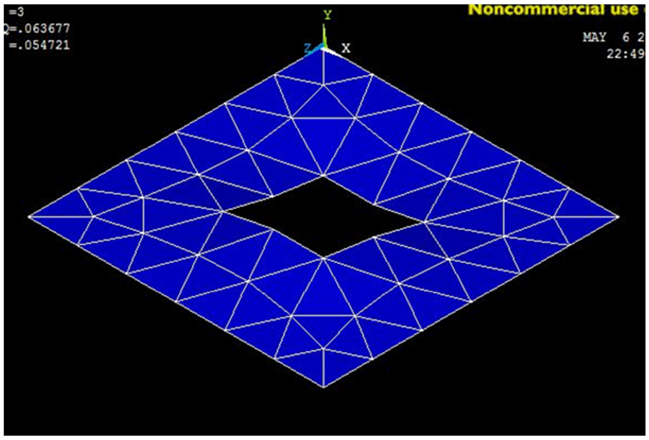

Fig 5.22: Mode shape of composite plate for simply supported condition.

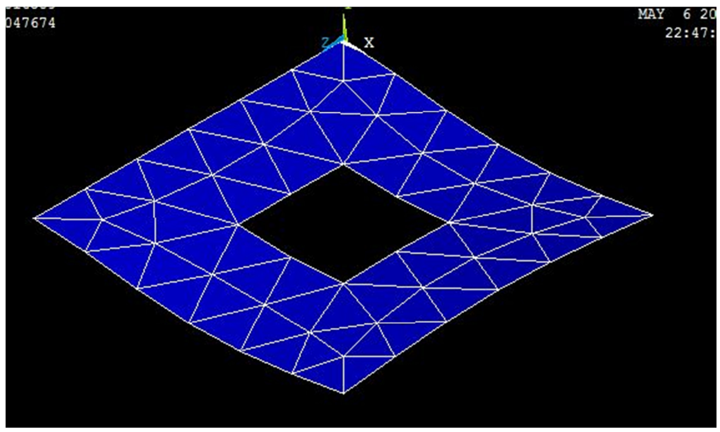

Fig 5.23: Mode shape of composite plate for cantilever condition.

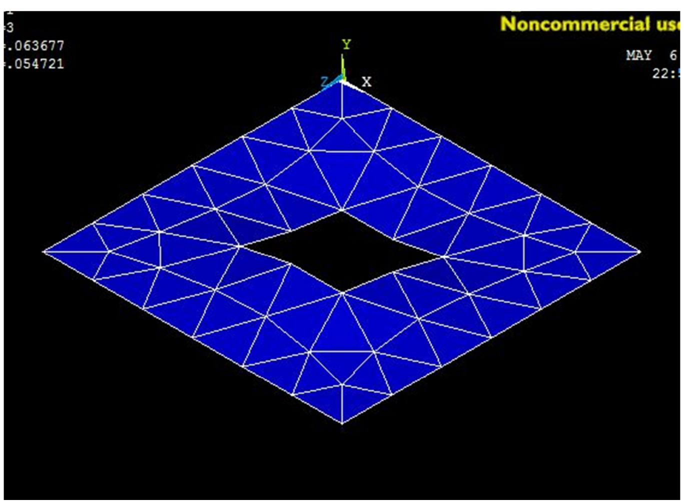

Fig 5.24: Mode shape of composite plate for fixed end condition.

CHAPTER 6

CONCLUSIONS

Based on the experimental results, data, tabulations and graphs the following inferences have been made:

Case 1: <u>Effect of change in size of cut out</u>:

- In all the cases involving the various boundary conditions it is found that there is significant change in frequency in case of cut outs on the plates.
- For the case of fixed end conditions, initially there is decrease in frequency in case of 36 cm2 and 64 cm2 cut out but a substantial increase when the cut out size is increased to 100 cm2.
- For simply supported and cantilever cases there is a steady decrease in frequency for all the modes with increase in the size of cut out.

Case 2: <u>Effect of change in aspect ratio of cut out</u>:

- In case of cantilever end condition at lower modes there is not much variation in modal frequencies with change in aspect ratio of the cut-out. But at higher modes the variation is significant.
- In case of simply supported end condition for all the modes there is a decrease in modal frequencies with increase in aspect ratio.
- However in fixed end conditions there is increase in modal frequencies with increase in aspect ratio which is substantial at higher modes.

Case 3: <u>Effect of change in layers of composite plate with same size of cut out</u>:

- Irrespective of end conditions there is an increase in modal frequencies with increase in no. of layers of composite plate.

- However in case of simply supported end condition rate of increase in modal frequencies is increasing as we go for more no. of layers.

Case 4: <u>Effect of change in position of cut-out on composite plate</u>:

- As the distance of cut-out from centre of plate increases, the frequencies for higher modes increases but mode 1 it is reducing. This is in case of simply supported end condition.
- However for fixed end condition with increase in distance of cut-out from centre the frequencies increases.

Case 5: <u>Effect of change in distance of cut-out from support on composite plate</u>:

- We can clearly observe from the graph that as we move from the support the frequency of the various modes increases for the first two modes.
- For the modes 3 and above the frequency decrease when we move further away from the central line.

Experiments were done with change in different types of cut-outs in the plates. It can be seen that cut-outs in plates can bring significant change in modal frequencies and mode shapes of the composite. However they impart different properties in modal strength of the plates for different styles of incorporation. So cut-outs must be incorporated in plates and other structures very cautiously keeping in mind the variations of the frequency it can cause due to change of its various parameters.

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